Cross sections and neutron emission spectra in fission of unstable actinide nuclei using surrogate reactions and direct neutrons

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Study of neutron induced fission of actinide nuclei has been the subject of fundamental and applied research since its discovery more than 75 years ago. In the past, tremendous effort has been put into studies of low energy actinide fission because of the particular importance of this process for nuclear energy applications. Nowadays, there is an increasing interest in studying neutron-induced fission of actinides at intermediate energies, *i.e.*, between 1 to 200 MeV due to worldwide interest in accelerator-driven systems (ADS) for nuclear energy applications. These future reactor systems promises the enhanced safety, reliability, sustainability, and waste reduction. An important component of the research and development for these reactor concepts is the improvement of the fundamental nuclear cross-section data. The unstable transuranic nuclide produced in the nuclear fuel cycles by successive neutron capture plays a prominent role in these new designs. Accurate data sets, especially neutron induced reaction cross sections with these unstable isotopes taking place at energies from several keV to tens of MeV, are important for engineering design of these reactor systems [1]. However all relevant data can not be directly measured in the laboratory or accurately determined by calculations. Direct measurements may encounter a variety of difficulties: many of these nuclei are too difficult to produce with currently available experimental techniques or too short lived to serve as targets in a present day experimental setup. In order to overcome the experimental limitations, various indirect methods have been proposed in recent years. The first part of the present thesis work focuses on the measurement of neutron induced fission cross-section for some unstable actinides by such an indirect method called "*the surrogate nuclear reaction method*". In the past, surrogate reaction methods in various forms such as the absolute surrogate method, the surrogate ratio method (SRM), and the hybrid surrogate ratio method (HSRM)[1] have been employed to get indirect estimates of the neutron-induced reaction cross sections of many short-lived target nuclei.

In the present thesis work, we present our investigations on determination neutron induced fission cross sections of ^{241}Pu($T_{1/2}$=14.4 yr), ^{234}Pa($T_{1/2}$=6.7 h), ^{239}Np($T_{1/2}$=2.36 d), and ^{240}Np($T_{1/2}$=61.9 m) by surrogate methods. The neutron induced fission cross section for ^{241}Pu(n, f) reaction are determined by surrogate ratio method [15] where, the ^{6}Li+^{238}U $\rightarrow$ ^{242}Pu* $\rightarrow$ fission and ^{6}Li+^{232}Th $\rightarrow$ ^{236}U* $\rightarrow$ fission reactions were used as surrogate of desired n+^{241}Pu $\rightarrow$ ^{242}Pu* $\rightarrow$ fission and n+^{235}U $\rightarrow$ ^{236}U* $\rightarrow$ fission reactions. Compound nuclei ^{242}Pu* and ^{236}U* were populated at overlapping excitation energies, and fission decay probabilities were measured in the excitation energy range 17 to 22 MeV. The SRM approach is then used to determine ^{241}Pu(n, f) cross section in the equivalent neutron energy range 11.0 MeV to 16.0 MeV by taking the corresponding energy ^{235}U(n,f) cross section values as the reference reaction. While the ^{234}Pa(n, f), ^{239}Np(n, f), and ^{240}Np(n, f) compound nuclear cross sections are determined by measuring the ratio of fission decay probabilities in [^{232}Th(^{7}Li,a)^{235}Pa / ^{232}Th(^{7}Li,t)^{236}U],[^{238}U(^{6}Li,a)^{240}Np / ^{238}U(^{6}Li,d)^{242}Pu], and [^{238}U(^{7}Li,a)^{241}Np / ^{238}U(^{7}Li,t)^{242}Pu] transfer reactions respectively employing HSRM [2–4].

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The accelerator driven systems consist of sub-critical reactors driven by the neutrons produced in a spallation subactinide target irradiated with high energy (up to GeV) protons. The energy of spallation neutrons is continuous from thermal up to the energy of the incident proton beam. This spallation process produces also energetic secondary protons which will still significantly contribute to the overall induced reactions. Neutron-and proton-induced reactions in this energy range are among the very important ones for the ADS design. The most probable process resulting from these reactions is fission, which will be accompanied by non-negligible neutron emission which will surely affect the subcriticality aspect of the proposed ADS reactor. Therefore, it is important to study neutron multiplicities and compare them with evaluations and predictions presently used for establishing the subcriticality concept and criteria of a reactor design. In connection with the coordinated research program launched by the International Atomic Energy Agency (IAEA), we have carried out a measurements on the prompt fission neutron spectrum (PFNS) in fast neutron - induced fission of major actinides such ^{238}U and ^{232}Th. In the second part of the present thesis work, we report the results of our research program, which focuses on measuring the PFNS emitted in the fast-neutron-induced fission of ^{238}U.

There are limited experimental studies on prompt fission neutron spectra for fast-neutron-induced fission. This situation is mainly due to the following difficulties: (a) small fission cross sections for the fast neutrons;(b) the large background produced in the same energy region as that of fission neutrons due to scattering of incident neutrons; (c) the fact that a monoenergetic neutron source of the required energy with the appropriate intensity is often not easily accessible. Prompt fission neutrons are characterized by two basic quantities: the average number of prompt neutrons emitted per fission, which is known up to 30 MeV with an accuracy of better than $1^{\%}$, and the shape of the neutron energy spectrum, which is not nearly as well known. The need for better knowledge of prompt fission neutron spectra for actinide nuclei is also reflected in the International Atomic Energy Agency (IAEA) request list. In the present thesis, we also report on some of the results of our research work, which focuses on measuring the PFNS emitted in the fast- neutron-induced fission of ^{238}U at incident neutron energies of 2.0, 2.5, and 3.0 MeV [5].

References

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